Special Article

Poverty and obesity: the role of energy density and energy costs[1,2]

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ABSTRACT
Many health disparities in the United States are linked to inequalities in education and income. This review focuses on the relation between obesity and diet quality, dietary energy density, and energy costs. Evidence is provided to support the following points. First, the highest rates of obesity occur among population groups with the highest poverty rates and the least education. Second, there is an inverse relation between energy density (MJ/kg) and energy cost ($/MJ), such that energy-dense foods composed of refined grains, added sugars, or fats may represent the lowest-cost option to the consumer. Third, the high energy density and palatability of sweets and fats are associated with higher energy intakes, at least in clinical and laboratory studies. Fourth, poverty and food insecurity are associated with lower food expenditures, low fruit and vegetable consumption, and lower-quality diets. A reduction in diet costs in linear programming models leads to high-fat, energy-dense diets that are similar in composition to those consumed by low-income groups. Such diets are more affordable than are prudent diets based on lean meats, fish, fresh vegetables, and fruit. The association between poverty and obesity may be mediated, in part, by the low cost of energy-dense foods and may be reinforced by the high palatability of sugar and fat. This economic framework provides an explanation for the observed links between socioeconomic variables and obesity when taste, dietary energy density, and diet costs are used as intervening variables. More and more Americans are becoming overweight and obese while consuming more added sugars and fats and spending a lower percentage of their disposable income on food. *Am J Clin Nutr* 2004;79:6–16.

KEY WORDS Poverty, food insecurity, obesity, education, income, energy density, food costs, added sugar, added fat, palatability, socioeconomic status

INTRODUCTION

Rising rates of obesity in the United States have been linked to food supply trends and to the growing consumption of energy-dense foods (1–4). An increased consumption of snacks (5), caloric beverages (6, 7), and fast foods (8) by children and young adults has been shown repeatedly to be associated with obesity and excess weight gain. Studies have examined the contribution to the obesity epidemic of dietary sugars and fats (6, 9), larger portion sizes (10), and the lower nutrient density of foods eaten away from home (11). The content of school lunches has been scrutinized (12), and even food-assistance programs have come under attack for their alleged role in "fattening the poor" (13, 14).

Public health policies for the prevention of obesity increasingly call for taxes and levies on fats and sweets, both to discourage their consumption and to help promote alternative and healthier food choices (15, 16). Past studies on dietary antecedents of obesity have addressed taste preferences for sugar and fat as well as preferences for energy-dense foods (17–19). In contrast, the relation between fat and sugar consumption, dietary energy density (MJ/kg), and energy costs ($/MJ) has not been explored. Establishing associative links between obesity, dietary energy density, and energy costs is the chief focus of this report

POVERTY AND OBESITY

Obesity rates in the United States have risen sharply over the past 2 decades (20–22). By 1999–2000, 64% of adults aged ≥ 20 y were classified as overweight and 30% were classified as obese. Overweight is defined as a body mass index (BMI; in kg/m^2) > 25, whereas obesity is defined as a BMI > 30 (20). A sharp increase in the number of massively obese people (BMI > 35) has been observed in certain population subgroups (23).

There is no question that the rates of obesity and type 2 diabetes in the United States follow a socioeconomic gradient, such that the burden of disease falls disproportionately on people with limited resources, racial-ethnic minorities, and the poor (20). Among women, higher obesity rates tend to be associated with low incomes and low education levels (21, 23–25). The association of obesity with low socioeconomic status (SES) has been less consistent among men (21, 25). Minority populations (except for Asian Americans) have higher rates of obesity and overweight than do US whites (21). Analyses of data for 68 556 US adults in the National Health Interview Survey by the Centers for Disease Control and Prevention showed that the highest obesity rates were associated with the lowest incomes and low educational levels (22). The relation between obesity and education and income, based on charts published by the Centers for Disease Control and Prevention (22), is shown separately for men and women in **Figure 1**. Although obesity rates have continued to increase

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Received March 18, 2003.
Accepted for publication June 9, 2003.

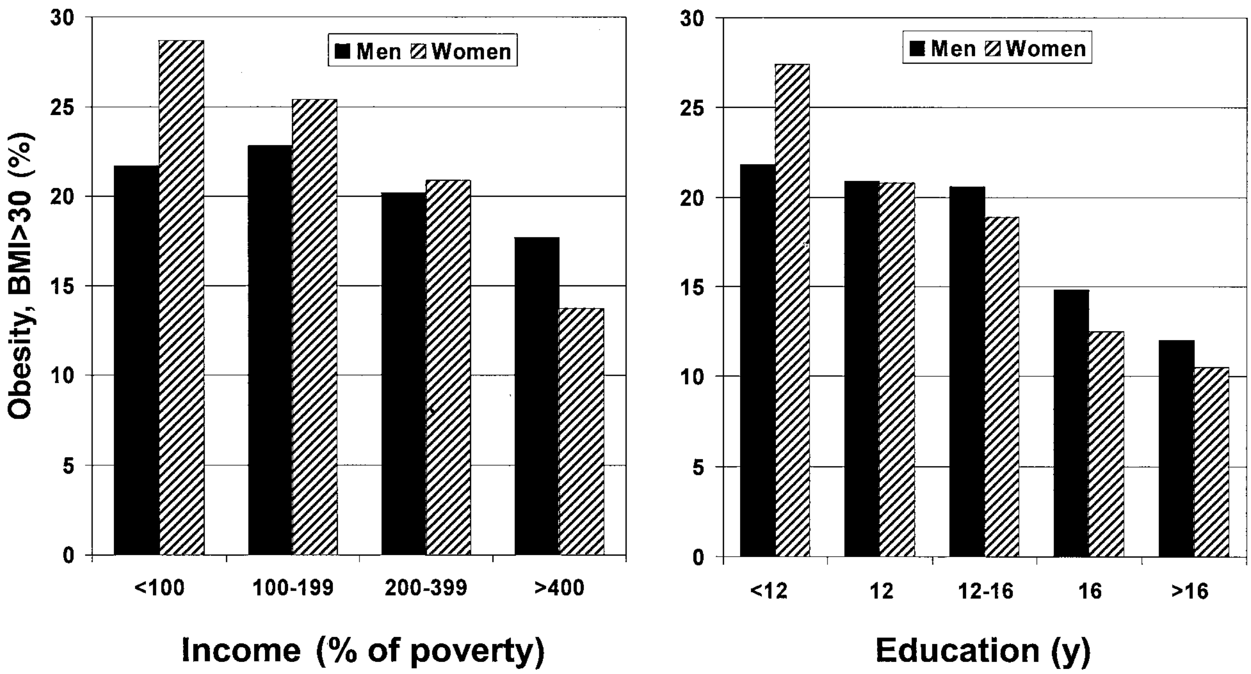

FIGURE 1. Obesity as a function of income and education. Adapted from reference 22.

steadily in both sexes, at all ages, in all races, and at all educational levels (26), the highest rates occur among the most disadvantaged groups.

Food insecurity and obesity also appear to be linked (27, 28). The concept of food insecurity, originally adapted from work by the Food and Agriculture Organization of the United Nations, was used to examine access to food by low-income households (29). Participants in the 1977–1978 Nationwide Food Consumption Survey were asked which of the following statements best described the food eaten in their household: "enough and the kind wanted to eat," "enough but not always the kind wanted to eat," "sometimes not enough to eat," or "often not enough to eat." These questions distinguished between food insecurity and overt hunger (28).

In the 1995 US Department of Agriculture (USDA) Current Population Survey, food insecurity was defined as "limited or uncertain availability of nutritionally acceptable or safe foods" (30, 31). The 1995 Current Population Survey judged 11.9% of all US households to be food insecure (30). However, not all food-insecure households showed evidence of hunger, and the relation between poverty, food insecurity, and hunger was a complex one (32, 33). There was no one-to-one correspondence between income-based measures of poverty and food insecurity, and only 13.1% of those in poverty were affected by hunger (34). Of the food-insecure households, 65% (7.8% of total) showed no evidence of hunger, 28% (3.3%) reported moderate hunger, and 6.9% (0.8%) reported severe hunger (30). There was also a positive association between food insecurity and participation in the Food Stamp Program (27), because food-insecure persons were more likely to seek food assistance.

In the third National Health and Nutrition Examination Survey (NHANES III), 1988–1994, food insufficiency was defined as "sometimes" or "often" not having enough to eat (27). The prevalence of food insufficiency was 4% in the total sample but as high as 14% among low-income respondents. According to the USDA Economic Research Service, 10.1% (10.5 million) of American households reported some level of food insecurity in 1999, including 9.5% of adults and 16.9% of children aged $<$ 18 y. Households with children were twice as likely to report food insecurity (35). Among low-income families, food insufficiency was associated with single-parent families, not having health insurance, and having a family head with $<$ 12 y of education.

Among women, food insecurity without hunger appears to be associated with overweight. Analyses of NHANES III data (28) showed that women, but not men, in food-insufficient households were more likely to be overweight than were food-sufficient women (58% compared with 47%). In another study, food-insecure women were $>$ 10 lb (4540 g) heavier on average than was the comparison group (36). Whereas links between food insecurity and lower diet quality might be expected, the association between food insecurity and overweight was something of a paradox (28). Given that low-income families are the chief beneficiaries of food-assistance programs, exploration of the causal connections between food insecurity and obesity has major implications for food and nutrition policies in the United States (28).

ENERGY-DENSITY COST FRAMEWORK

In 1992, Basiotis (37) hypothesized and confirmed a behavioral model in which household members faced with diminishing incomes first consumed less expensive foods to maintain energy intakes at a lower cost. To multiple-choice questions about food sufficiency, these participants responded "enough but not the kinds of food we want to eat," which implied adequate energy intakes but a limited range of food choices. Only when incomes diminished still further did households reduce dietary energy to intakes below daily requirements, which resulted in overt deprivation. The food-insufficiency

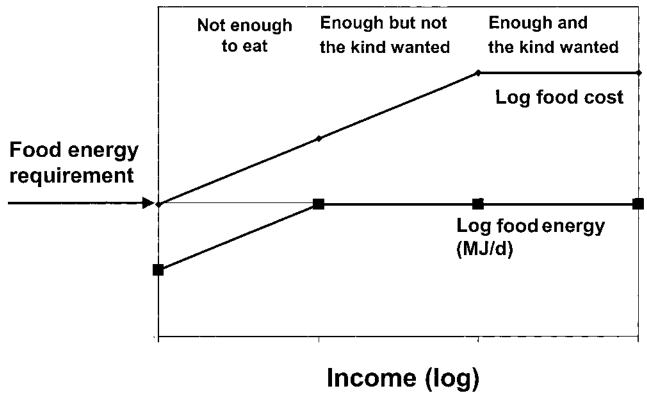

FIGURE 2. Food-insufficiency curve showing the relation between incomes, food costs, and energy intakes by 3 categories of response to food-insufficiency questionnaires. Adapted from reference 28.

curve, linking household incomes with food costs and energy intakes, is shown in **Figure 2** (28, 37). Food restriction at home first occurs in adults because parents typically turn over their own food to children when resources are scarce (38).

In the present framework, the association between poverty and obesity is mediated, at least in part, by the low cost of energy-dense foods, which may in turn promote overconsumption. The hypothesis is that energy density (MJ/kg) and energy costs ($/MJ) are inversely linked, such that the selection of energy-dense foods by food-insecure or low-income consumers may represent a deliberate strategy to save money. Analogous to the findings of Basiotis (37), persons attempting to limit food costs will first select less expensive but more energy-dense foods to maintain dietary energy. The energy-cost curve linking food costs with dietary energy density and energy intakes is shown in **Figure 3**. As food costs diminish further, dietary energy density rises, and total energy intakes may actually increase. Some of the evidence linking dietary energy density with higher energy intakes is outlined below.

ENERGY DENSITY INFLUENCES ENERGY INTAKES

Energy density of foods (MJ/kg) is said to be the key influence on daily energy intakes (17, 39). Under laboratory conditions, people consume a constant volume of food at a given meal such that the energy density of foods determines the amount of energy consumed (40). In experimental studies, palatable energy-dense foods have been associated with diminished satiation and satiety (40, 41), "passive overconsumption" of fats and sweets (42), and higher energy intakes overall (39, 43). In contrast, bulky foods with a high water content are said to promote a feeling of fullness, which leads to reduced energy intakes both at the test meal and throughout the day (44).

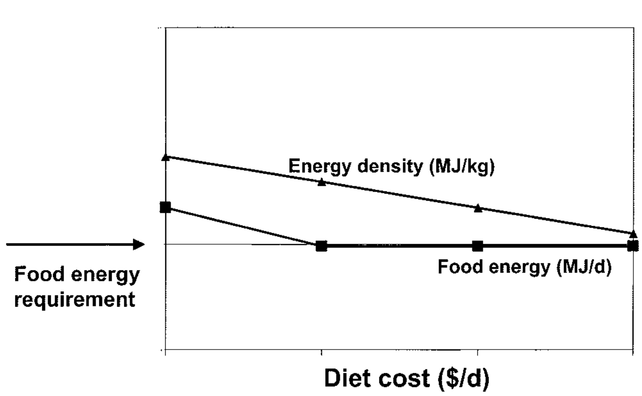

FIGURE 3. Energy density–cost curve showing the relation between diet costs, dietary energy density, and energy intakes.

The energy density of foods is a function of their water content (17). Whereas energy-dilute foods are heavily hydrated, energy-dense foods are dry and may also contain fat, sugar, or starch (17, 39). Potato chips (23 kJ/g), chocolate (22 kJ/g), and doughnuts (18 kJ/g) are energy-dense foods. Dairy products vary in energy density, from dry cheeses (17.0 kJ/g) to yogurt (4.2 kJ/g) to fluid low-fat milk (1.6 kJ/g) (17). Because of their high water content, the energy density of raw vegetables and fruit is low ($\approx$0.4–2.0 kJ/g). Beverages with different nutrient compositions may have the same energy density; for example, the energy density of 1% milk, orange juice, and cola is 1.8 kJ/g (17, 43). Several studies have suggested that water contained in foods has a more pronounced effect on satiety than does water contained in beverages (40, 44). Foods with a high moisture content, such as vegetables and fruit, allow the consumer to "feel full on fewer calories" (40).

Whereas the energy density of foods can be obtained from nutrient-composition tables, calculation of the energy density of the total diet is more difficult. Such calculations generally include all foods and caloric beverages but exclude noncaloric beverages and water (45–47). In some cases, both caloric and noncaloric beverages were excluded (45, 46). High-energy-density diets are those that include more fast foods, snacks, and desserts, whereas diets lower in energy density are those that are higher in vegetables and fruit (48). Higher dietary energy density tends to be positively associated with total energy intakes and with the percentage of energy from fat (45). In the United States, the energy density of the children's diets was inversely associated with the percentage of energy from sugars, most likely because of the high consumption of energy-dilute soft drinks (45). However, the relation between dietary energy density and overweight has been difficult to establish, given that it is confounded by age and energy expenditure. High energy intakes in cross-sectional studies need not be evidence of hyperphagia, but may reflect the higher energy intakes of younger or more active persons (39). No community-based data have shown a causal connection between dietary energy density and overweight.

ENERGY-DENSE FOODS ARE MORE PALATABLE

Studies using laboratory animals have found sugar and fat to be powerful sources of neurobiological reward (49, 50). Foods that are energy-dense provide more sensory enjoyment and more pleasure than do foods that are not (51–53). Clinical studies suggest that the most likely targets of food cravings are those foods that contain fat, sugar, or both (54). In times of dietary scarcity, human preferences for energy-dense foods represented an advantage in survival (43).

Human taste preferences for sugar and fat are either innate or acquired very early in life (55). Studies with children have consistently shown that familiarity, sweetness, and energy density are the chief determinants of food preference (56). Very young children learn to prefer novel nonsweet flavors once the flavors have been associated with a concentrated source of

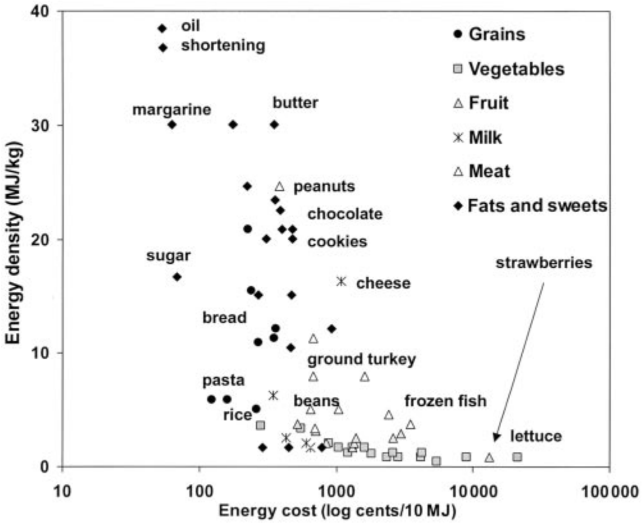

FIGURE 4. Relation between the energy density of selected foods and energy costs ($/MJ). Food prices were obtained from Quality Food Centers supermarket, Seattle, winter 2003. Note that the energy cost differential between added sugars and fats and fresh vegetables and fruit can be several thousand percent, as indicated by the logarithmic scale.

energy, such as starch or fat (56, 57). Studies of the food preferences of 3–4-y-old children showed that preferences were driven by familiarity and the energy density of the foods (58). Children preferred the more energy-dense foods and gave higher ratings to chocolate cookies and potato chips than to vegetables and fruit (58).

Preferences can also be shaped by repeated exposures (59, 60) or by a positive association with postingestive metabolic consequences of a food (61, 62). Mothers may also influence children's food choices through their own preferences. In a recent study, based on proxy reports, mothers indicated that their children liked energy-dense foods such as pizza, chocolate chip cookies, and sweetened breakfast cereals, whereas low-energy-density tomatoes, cucumbers, and cabbage were disliked by children and their mothers (62). Whether induced by innate taste preferences, early exposure, or other environmental factors, long-term dietary exposure to sugar and fat may have permanent metabolic consequences on the organism (50).

HIGH ENERGY DENSITY MEANS LOW ENERGY COSTS

Developments in agriculture and food technology have made energy-dense foods accessible to consumers at a very low cost (63–65). The relation between the energy density (MJ/kg) of selected foods and their energy cost (cents/10 MJ) is shown in **Figure 4**. Energy density values were taken from food composition tables and from Rolls and Barnett (40), whereas energy costs were based on supermarket prices in Seattle collected in the winter of 2003. The energy cost of cookies or potato chips was ≈20 cents/MJ (1200 kcal/$), whereas that of fresh carrots was ≈95 cents/MJ (250 kcal/$). The energy cost of soft drinks was, on average, 30 cents/MJ (875 kcal/$), whereas that of orange juice from concentrate was 143 cents/MJ (170 kcal/$). Fats and oils, sugar, refined grains, potatoes, and beans represented some of the lowest-cost options and provided dietary energy at minimal cost. As indicated by the logarithmic scale, the differential in energy costs between sugar and strawberries was in the order of several thousand percent.

The hierarchy of food prices is such that dry foods with a stable shelf life are generally less costly (per MJ) than are perishable meats or fresh produce with a high water content. As a rule, potato chips, chocolate, and locally bottled soft drinks provide dietary energy at a lower cost than do naturally hydrated lean meats, fish, and fresh vegetables and fruit. Energy-dense foods may contain a relatively high proportion of refined grains, added sugars, and vegetable fats.

The current US diet derives close to 50% of energy from added sugars and fat (63, 64). Data from the Economic Research Service of the USDA (65) show that the per capita availability of caloric sweeteners and fats and oils each increased by ≈20% between 1977 and 1997. Retail price increases during that time were much lower for sweets and fats than for vegetables and fruit. Other studies have shown that foods identified as accounting for the greatest increase in energy intake by Americans during that time were salty snacks, desserts, soft drinks, fruit drinks, hamburgers and cheeseburgers, Mexican food, and pizza (66). In 1977–1978, these foods combined accounted for 18.1% of the dietary energy consumed by Americans ($>$ 2y) and for 27.7% of energy in 1994–1996. For the most part, many such foods are composed of refined grains, added sugars, and fats.

Studies on dietary choices leading to obesity have focused overwhelmingly on the sugar and fat content of snacks, fast foods, beverages, and confectionery (67, 68). Epidemiologic studies have linked diets composed of fats and sweets, potatoes, and refined grains with higher glycemic indexes and a higher risk of obesity and type 2 diabetes (69). Obese patients were accordingly advised to replace fats and sweets with a more prudent dietary pattern characterized by a high intake of fruit, vegetables, whole grains, poultry, and fish (70, 71). Among public health measures for the prevention of obesity are the need to restrict the consumption of energy-dense snacks and sugar-sweetened soft drinks and to increase the consumption of whole grains and energy-dilute vegetables and fruit (15).

The inverse relation between energy density and energy cost suggests that "obesity-promoting" foods are simply those that offer the most dietary energy at the lowest cost. Given the differential in energy costs between energy-dense and energy-dilute foods, the advice to replace fats and sweets with fresh vegetables and fruit may have unintended economic consequences for the consumer (71).

INCOME DISPARITIES AFFECT DIET QUALITY

Prices and incomes affect food choices, dietary habits, and diet quality. The Healthy Eating Index (HEI)—a 10-component, 100-point scale developed by the USDA—is a measure of the quality of the total diet (72). The first 5 components measure the degree to which a given diet conforms to the food guide pyramid in the consumption of grains, vegetables, fruits, milk products, and meat. The next 5 components measure fat, saturated fat, cholesterol, and sodium intakes as well as the variety of foods in the diet. An HEI score of 80 implies a "good" diet, a score between 51 and 80 implies that a diet "needs improvement," and a score $<$ 51 indicates a "poor" diet (72, 73).

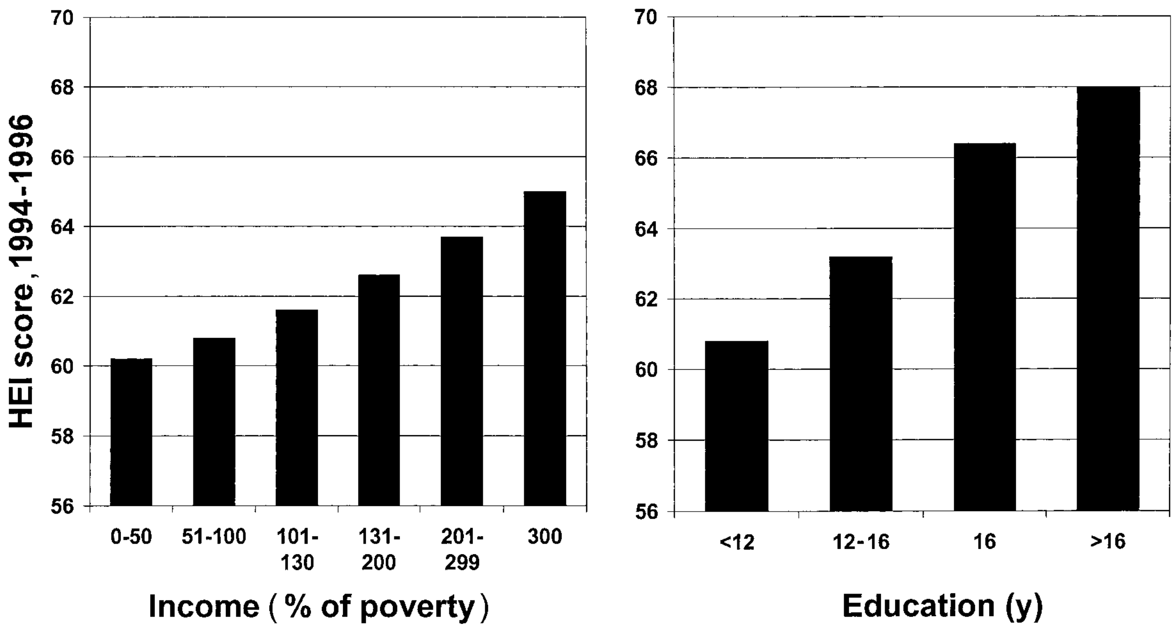

FIGURE 5. Diet quality, on the basis of Healthy Eating Index (HEI) scores, as a function of income and education. Adapted from reference 75.

Income disparities had more of an effect on diet quality than on total energy intakes. HEI scores were typically higher for women than for men and improved with increasing age, education, and income (72, 74). **Figure 5**, which is based on 1994–1996 CSFII (Continuing Survey of Food Intakes of Individuals) data, it is shown that HEI scores were higher for the wealthier and better-educated groups. Education had a stronger effect on diet quality than did incomes. Although African Americans had the lowest HEI scores, scores for Latinos and Asians were no different from those for whites. Strong associations between higher household incomes and higher quality diets were also obtained in studies conducted in Canada (76), France (77), the United Kingdom (75, 78–80), and other countries of the European Union (81, 82).

Women reporting food insufficiency had lower quality diets (28). Mean HEI scores in the 1988–1994 NHANES III data set were 58.8 for women in food-insufficient households compared with 62.7 for women in food-sufficient households. Food-insufficient women had lower HEI component scores for fruit (2.2 compared with 3.4), vegetables (5.1 compared with 5.8), milk (5.2 compared with 6.1), and food variety (6.4. compared with 7.3) and were less likely to comply with the cholesterol guidelines (7.4 compared with 8.2). Women in food-insufficient households consumed the same amount of energy as did women in food-sufficient households (1959 compared with 1868 kcal/d). Although the energy density of the diet was not calculated, energy-dense diets are those that contain the least fruit, vegetables, and milk. Limited economic resources appeared to have an adverse effect, not so much on dietary energy, but rather on the overall quality and, potentially, the energy density of the diet (28).

Health disparities among US population groups are related to inequalities in SES (20). Some of these disparities may be mediated by an unequal access to a healthy diet (83, 84). Whereas "good" diets were associated with higher education and incomes, "poor" diets were associated with overweight. In USDA studies (72), female CSFII respondents aged $>$ 19y with "poor" diets had a BMI of 26.4 compared with 24.8 for females whose diets were "good." For males, "poor" diets were associated with a BMI of 26.8, as opposed to 25.7 for "good" diets (72).

The effect of SES variables on diet quality has normally been ascribed to a higher educational level or to a greater awareness of health issues among higher-income respondents (72). However, nutrition knowledge alone does not necessarily lead to a healthy diet (85–87). Another possibility is that healthier diets cost more and are beyond the reach of many low-income families.

DO HEALTHY DIETS COST MORE?

Data from the Bureau of Labor Statistics indicate that income disparities do affect diet quality. Food purchases made by high-income households differed markedly from those made by low-income households (88). In 1992, households in the top quintile by income (mean income: US$77 311/y) spent US$1997/person (2.6% of total expenditures) for food, compared with US$1249 (18.7%) spent by those in the bottom quintile (mean income: US$6669/y). Wealthier households bought higher-quality meats, more fish and seafood, more fruit and vegetables, and more convenience foods. Despite buying lower-cost items, poor households devoted a far greater share of their disposable income to food. Their level of satisfaction with the perceived quality of the diet was not reported.

To achieve a healthy diet it may be necessary to spend more money (77, 79, 84). The UK Women's Cohort Study (89) is one of the few observational studies to have explored food costs, perceived and actual, in a study cohort of 15 191 women aged 35–69 y. Women in the healthiest diet group spent an additional 617 pounds sterling (≈US$1000) per year on food relative to the least-healthy diet group, with vegetables and fruit accounting for the largest amount of the cost. Yet almost 71% in the healthiest diet group and 60% in the least-healthy group did not agree that it was more expensive to eat a healthier diet, contrary to evidence obtained from the study itself. Cade et al (89) concluded that the individual assessment of diet costs was, to a large extent, a matter of subjective perception rather than of objective facts.

There is substantial evidence that food purchases are influenced by food costs (90–93). Several studies have mentioned diet costs as a barrier to dietary change, especially among low-income respondents (79, 84, 92, 93). Dietary variety and the consumption of fresh produce were generally associated with higher food costs. In USDA studies, total energy intakes or percentage of energy from fat varied little with incomes or participation in the Food Stamp Program (FSP) (84, 94). In contrast, a greater dietary variety and higher consumption of vegetables and fruit were associated with higher education and higher income levels (74, 76, 92). Recent USDA/Economic Research Service analyses of food and nutrient intakes by income, defined in relation to poverty status, showed the same link between incomes and diet quality (94). Although there was not much difference in energy or macronutrient intakes by income and no difference in the consumption of basic commodities (milk, meat, and grains), there were major income-related differences in the consumption of (among other foods) lettuce and lettuce-based salads; melons, berries, and other fruit; (94), and carbonated sodas. The proportion of women consuming salads and fruit on a given day was double for the highest-income group (> 350% poverty) relative to the lower-income group (< 131% poverty) (94).

Observational data on the costs of freely chosen diets are limited. The Consumer Expenditure Survey, conducted by the Bureau of Labor Statistics, collects household data on food expenditures for the Consumer Price Index (95). The USDA CSFII provides data on individual food consumption and nutrient intakes (96). The Consumer Expenditure Survey does not report quantities of foods purchased, whereas the CSFII does not collect data on the cost of the foods consumed. Neither database can provide information about diet quality in relation to diet costs. The USDA Food Stamp Survey does report food use and food price data but it is limited to food-assistance recipients. Further studies on diet quality in relation to diet costs represent a major research need (88, 94). As yet, there are no data that would allow us to link all of the dietary and economic variables into a causal chain.

In the absence of large-scale community studies, few intervention studies purport to show that healthful diets are not more expensive than are less healthful diets. One study (97), based on only 20 families with an obese 8–12-y-old child undergoing treatment, and a high attrition rate (20/31) showed that a decrease in family energy intakes from 1881 to 1338 kcal/person was indeed associated with a decrease in diet costs from US$6.77 to US$5.04. However, energy costs per 1000 kcal actually increased by > 10% (from US$3.69 to US$4.11). Nonetheless, the authors concluded that a more healthful diet was not more expensive than the typical American diet (97).

FOOD SPENDING IN THE UNITED STATES

The share of income spent on food decreases as incomes increase (98). Because incomes have increased faster than food costs, average food expenditures in the United States have dropped to only 10.7% of incomes in 1997 (99). In 1997, Americans spent 9.4% of their disposable income on foods consumed at home but only 6.6% in 1997 (99). Percentage

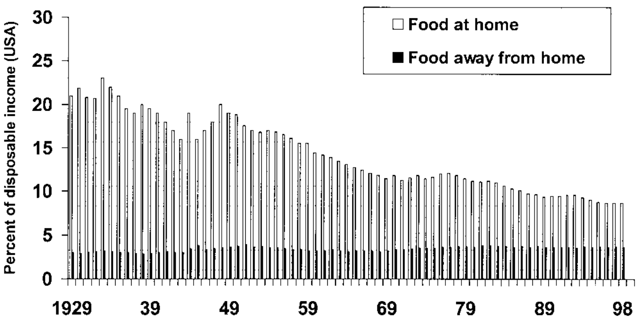

FIGURE 6. Share of disposable income spent on food by families and individual persons in the United States from 1929 to 1998. Adapted from reference 64.

expenditures on foods away from home decreased slightly from 4.2% to 4.1%. These data are presented in **Figure 6**. The drop in food spending was disproportionately greater than the drop in spending on other goods.

By 1999, total daily expenditures on foods and beverages (including alcohol) were estimated at just under US$8.00 per person. Assuming a daily ration of 10.5 MJ (2500 kcal), the estimated mean energy cost of the total diet was 76.9 cents/MJ. Other USDA estimates of the mean energy costs of the American diet were even lower, at 41.6 cents/MJ (65). Among industrialized nations, lower energy costs are generally associated with higher energy intakes (64, 65).

The corollary of Engel's Law (98) is that low-income families spend a higher proportion of disposable income on food. Whereas households with incomes > US$70 000/y spent 7% of after-taxes income on food, low-income families (range: US$10–15 000/y) spent close to 25% (99). Food costs were an issue, especially for low-income families and elderly female respondents. Focus groups conducted with FSP participants reported that all groups reported food price as the most important consideration in making food choices (100, 101). As noted in a report by Basiotis et al (100), "the most important factor in choosing and preparing foods was to ensure that no one would complain they are still hungry."

Economic factors may help explain why low-income respondents are least likely to eat healthy diets and suffer from some of the highest rates of obesity and type 2 diabetes (20). We hypothesize that consuming energy-dense foods, and energy-dense diets, is an important strategy used by low-income consumers to stretch the food budget. Energy-dense foods carry a lower price tag, which allows for a higher energy consumption at a lower cost (64, 71). Energy-dense foods also tend to be well-liked, even perceived as a reward—a factor that would reinforce their initial selection and repeated consumption. In general, taste is rated ahead of health and variety as an influence on food purchases and consumption patterns (102).

REDUCTIONS IN COST INCREASE ENERGY DENSITY

Very few studies have modeled diet composition after the imposition of cost constraints. One obstacle is posed by the lack of large data sets on food prices or food expenditures. In the absence of food-expenditures data, the USDA used mean national food prices based on the 1989 CSFII to estimate diet costs (103). That calculation served as the basis for the USDA Thrifty Food Plan (TFP), a national standard for a nutritious

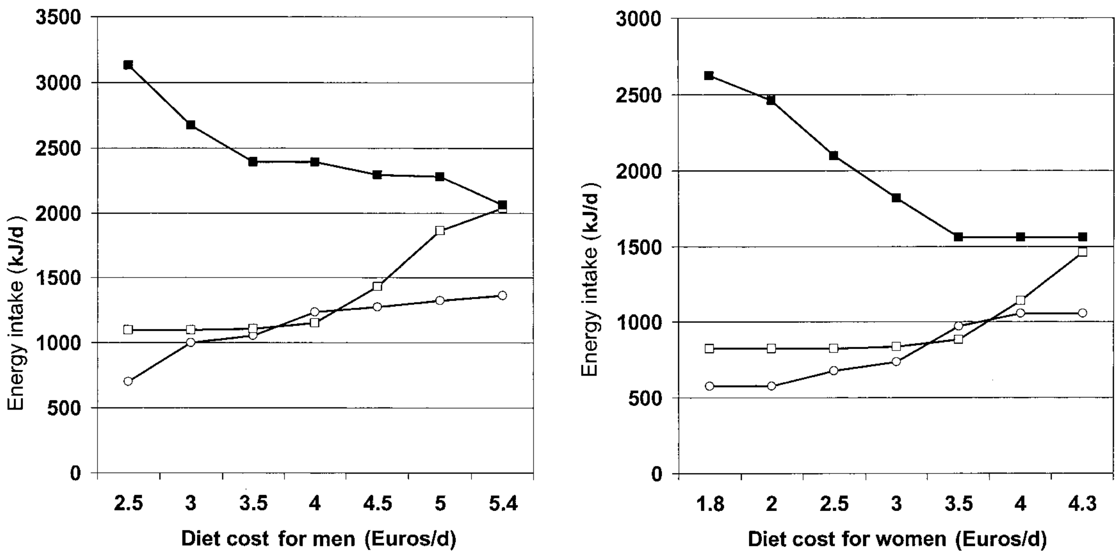

FIGURE 7. Change in energy intakes from different food sources in men and women from the Val-de-Marne data set after the imposition of cost constraints. ○, fruit and vegetables; □, meat, fish, and eggs; ■, fats and sweets. 1 Euro = US$1.1. Adapted from reference 106.

diet at a minimal cost that is used as the basis for food stamp allotments (104, 105). The TFP "market basket" is composed of 44 foods, is based on a mathematical optimization model that uses as inputs food guide pyramid servings, average daily consumption, nutrient composition of foods, and the average food price. Each TFP market basket identified the type and quantity of foods that people in different groups, by sex and age, might consume to achieve a healthful diet (104).

The foods were selected by using a nonlinear programming model that selected diets meeting specified nutritional criteria, with individual foods subject to cost constraints. Palatability was considered, but foods were not optimized for this objective. Given nutritional and cost constraints, the recommended foods featured grains and legumes, low-cost meats, and added sugars and fat. Among the foods recommended for a week for a family of 4 were potatoes (12 lb, 5443 g), pasta and rice (6 lb, 2722 g), beans (3 lb, 1361 g), bread (3 lb, 1361 g), sugar (1 lb, 454 g), lemonade (1 gallon, 3.8 L), added fats (2 lb, 907 g), frozen turkey (5 lb, 2268 g), and frozen orange juice (6 lb, 2722 g). The allotment of leaf lettuce was 4 oz (113 g)/wk, which reflects sharply higher energy costs for fresh produce. In 1999, the cost of TFP foods for the "reference family" (men and women aged 20–50 y with 2 children aged 6–8 y and 9–11 y) that met food guide pyramid guidelines was US$98.40/wk. This cost is equivalent to US$3.50 $\cdot$ person^{-1} $\cdot$ d^{-1}, the amount of food stamp benefits.

A recent study conducted in France used linear programming to model the composition of the French diet after the imposition of cost constraints (106). Analyses were based on dietary data for 837 adults that had been collected in an observational study in the Val-de-Marne region (107, 108). Nutrient analyses were based on a food-composition table, which was developed by the French National Institute of Health and Medical Research. Estimated national prices for 55 foods—excluding baby foods, rarely consumed foods, and alcohol—were added to the database. The prices were provided by the National Institute of Statistics and Economic Studies and were supplemented with retail prices from supermarkets in the Paris area. Linear programming was designed to be consistent with the usual food consumption in France and to minimize any departure from the usual French diet.

The imposition of cost constraints reduced the proportion of energy contributed by fruit, vegetables, meat, and dairy products and increased the proportion of energy contributed by cereals, added fats, and sweets. The resulting diet was identical in composition to that observed among lower-SES groups and contained the least amounts of β-carotene and vitamin C. Consistent with the energy-cost hypothesis, a reduction in diet costs led to diets high in added sugars and fats, as shown in **Figure 7**.

A US study on the cost benefits of nutrition education for food-assistance recipients (109) provides a rare look at diet quality and diet cost. In that study, 371 low-income women enrolled in the Expanded Food and Nutrition Education Program recorded the amount of money spent monthly on food at the time of program entry and exit. The Expanded Food and Nutrition Education Program, implemented by state land-grant universities in the United States, is intended to help the nutritional welfare of low-income families. In that study, a saving of US$10–20/mo in family food expenditures was associated with a net increase of 300 kcal/d in daily energy intakes and a significantly higher consumption of carbohydrates (43 g/d). The associated increase in fat intake (8 g/d) was not significant. Neither energy density nor added sugar consumption were measured (109).

OBESITY AND FOOD-ASSISTANCE PROGRAMS

Studies of diet quality and food assistance generally use regression models to explain the effects of economic and demographic variables, including program participation and benefit levels, on one or more food consumption variables (94). For the most part, the dependent variables are intakes of food energy, protein, and selected micronutrients. The results were decidedly mixed (84, 94). Whereas FSP participation had positive and significant effects on the consumption of some foods, other nutrient needs were not always met (88, 94, 110).

Few low-income households meet the twin objectives of spending less than the TFP amount and buying foods that contribute to a healthful diet (110). Those few people that did meet these objectives spent a larger share of the food dollar on grains, fruit, vegetables, and milk and less on meat, soft drinks, sweets, fats, and alcohol. However, according to USDA surveys, most low-income respondents spent their limited food dollars on energy-dense foods that were largely composed of added sugars and fat (88, 94).

Studies that used more global measures of diet quality were more successful in showing the benefits of the FSP or the Supplementary Nutrition Program for Women Infants and Children (WIC). These studies found that the consumption of the 5 main food guide pyramid food groups (ie, those other than fats and sweets) increased as incomes increased (100). Studies conducted by the Center for Nutrition Policy and Promotion using 1989–1991 CSFII data (100) found that WIC participation and, to a lesser extent, the FSP were associated with higher-quality diets, as indexed by HEI scores. Otherwise, little is known about the effects of food-assistance programs on diet quality and dietary energy density. Another research gap concerns measures of acceptance for individual foods and participant satisfaction with the overall quality of the diet. Such information would be useful in tracking satisfaction with food choices provided or recommended by food-assistance programs.

OBESITY: AN ECONOMIC HYPOTHESIS

Food choices and energy intakes in obesity have been explained in terms of biology, physiology, and behavior. The biological explanation has been that taste preferences or "cravings" for sweet and high-fat foods are driven by central metabolic events, such as serotonin imbalance, altered concentrations of leptin or neuropeptide Y, or the endogenous opiate peptide system (49, 50). Physiologic explanations have invoked the glycemic index of foods, insulin resistance, and adipose tissue metabolism (70). Psychological explanations have addressed inadequate nutrition knowledge, excessive vulnerability to the external environment, addictive personality, and the consumption of high-fat foods in search of comfort (111). Environmental approaches have blamed the wide availability of snacks, fast foods, and soft drinks; the presence of vending machines in schools; and the phenomenon of "supersizing" of fast foods eaten outside the home (67).

Television advertising has been cited as a factor contributing to higher energy and fat intakes (112, 113) and so has the marketing of energy-dense foods (15). In 1997, food manufacturers, food retailers, and food services reportedly spent US$11 billion on advertising, much of it on foods containing added sugars and fat (8). Studies suggest that some of this advertising may be targeted at children and at low-income consumers (113). As indicated above, such foods provide energy at a much lower cost than do fresh vegetables and fruit, which are perceived as luxury items and are not always easily accessible. Growing portion sizes are another example of how the food industry provides inexpensive extra energy at lower unit cost. The most commonly cited examples of supersizing (114) tend to involve foods composed of refined grains, added sugars, and fat.

The notion of the economic costs of obesity invariably refers to the costs of obesity and related diseases to society (115).

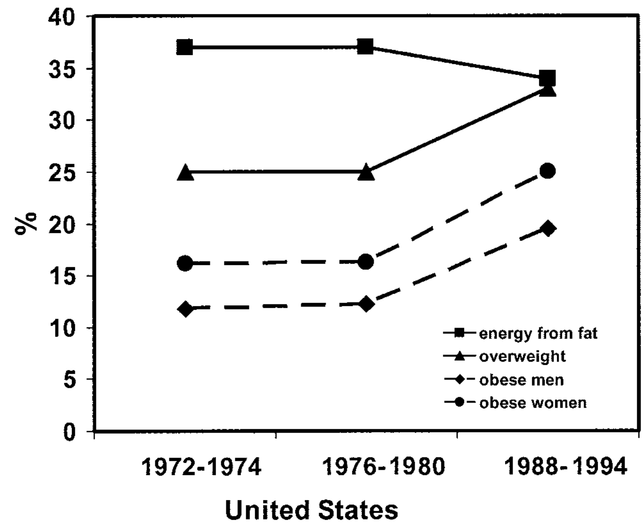

FIGURE 8. Change in dietary fat intake and the percentage of the population that was overweight or obese in the United States from 1972 to 1994. Adapted from reference 116.

There has been little emphasis on the low economic costs of becoming obese. At world market prices, the cost of refined sugar is $\approx$10 cents/lb (454 g). In other words, close to 80 000 kJ can be purchased for $US1 (64). The current economic hypothesis is that high energy intakes, not only in the United States but worldwide, may be driven by the very low cost and reinforced by positive hedonic properties of energy-dense foods.

Obesity has been linked with the excessive consumption of both sugars and fats. Whether fat as opposed to sugar consumption is to blame is a controversial issue (9, 116–118). Some researchers believe that excessive carbohydrate, as opposed to fat, consumption is responsible for the current obesity epidemic. This argument rests on the observation that the percentage of energy from fat decreased from 38% to 34% between 1976–1980 and 1988–1991, whereas the prevalence of obesity increased (116–118).

The relation between a rise in obesity rates and the decrease in the percentage of energy from fat was shown previously (116) and is illustrated in **Figure 8**. The exact same inverse relation can be shown for a rise in obesity rates and the decrease in the percentage of disposable income that is spent on food (**Figure 9**). In reality, both incomes and total fat con-

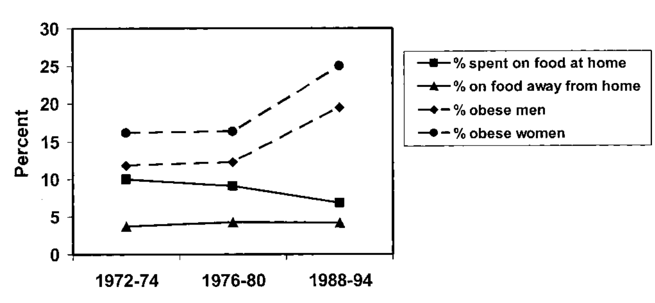

FIGURE 9. Change in the percentage of disposable income spent on food at home and away from home and the percentage of the population that was obese in the United States from 1972 to 1994. Reprinted with permission from reference 64.

sumption (in g/d) have continued to increase, as have total energy intakes. One mechanism to hold down diet costs is to increase the energy density of the diet through the consumption of more grains and added sugars and fats. Obesity rates increase as energy intakes increase, but food spending (as a percentage of income) decreases disproportionately relative to spending on other goods.

OBESITY AS A PUBLIC HEALTH PROBLEM

Consumer food choices are driven by taste, cost, and convenience, and to a lesser extent by health and variety (102). Research has linked growing obesity rates with a growing consumption of snacks, fast foods, and soft drinks (1–9) and with the consumption of high-energy-density diets. What energy-dense foods have in common is low energy cost, due in part to the presence of added sugars and fat. Some nutrition professionals have already noted that diets consumed by groups with a lower SES provide cheap, concentrated energy from fat, sugar, cereals, potatoes, and meat products but very little intake of vegetables, fruit, and whole grains (90, 91). Yet any discussion of dietary energy density in relation to diet costs has been missing from the mainstream literature on the determinants of obesity in the United States. Our central hypothesis is that limited economic resources may shift dietary choices toward an energy-dense, highly palatable diet that provides maximum calories per the least volume and the least cost.

The hypothesis that healthier diets may indeed cost more has many policy implications. One issue is whether economic incentives can promote healthful eating more effectively than do current strategies, on the basis of theoretical models for behavioral change. The USDA has linked a lower consumption of added sugars among WIC participants to the provision of WIC-supplied juices and cereals (94). There are also studies on price supports for vegetables and fruit and on the manipulation of snack prices in vending machines to encourage the consumption of lower-fat items (119). If this economic approach is to be successful, we need a better understanding of how food prices affect consumer food choices and the selection of a healthy diet.

Reducing the energy density of the diet is a worthy objective; the question is, can it be achieved without simultaneously increasing the cost and reducing the palatability of the diet? If long-term compliance with recommended diets is to be achieved by persons with a limited food budget, the foods must be affordable and acceptable (120). More work is needed to explore strategies for systematically shifting taste and food preferences in the direction of less energy-dense foods. A shift to a diet with a greater emphasis on fruit, vegetables, and whole grains would be consistent with the gradual change in consumption from full- to reduced-fat dairy products seen over the past 30 y (121).

The current focus of obesity research has been on environmental factors that promote inactive lifestyles and excess energy intakes (122). The present economic approach suggests that food choices and diet quality are influenced by social and economic resources and by food costs. Low-cost, energy-dense diets are likely to contain added sugars and vegetable fats. Such diets have been and will continue to be associated with obesity and overweight. However, the relevant features of obesity-promoting diets may not be the percentage of energy from sugar or fat (119, 120) but rather high palatability and low energy cost. These issues are inextricably linked to agricultural commodity prices, imports, tariffs, and trade. Americans are gaining more and more weight while consuming more added sugars and fats and are spending a lower proportion of their income on food. No longer a purely medical issue, obesity has become a societal and public health problem.

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